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Development of foliage biomass of young spruce and beech stands in the mountain water balance research area

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ABSTRACT: The investigation of foliage biomass development including LAI and the growth of spruce and beech stands in the juvenile stage (age 1 to 21 years) represents a special complementary study to long-term research of water balance components on the experimental forest hydrology area Deštné Mountainside. The experiment is located in the Orlické hory Mts. at the altitude of 900 m on a clear-felled area. In 1982 the spruce plantation was established at 1.5 × 1.5 m spacing (4,600 plants/ha) and the beech plantation at 1.0 × 1.0 m (10,000 plants/ha). According to tending programs applicable to forest stands in the Czech Republic, two improvement fellings were carried out (1995 and 2001) in spruce and none in beech. In 2002, some 1,550 spruce trees/ha (mean height 10.1 m) and 7,440 beech trees/ha (mean height 4.8 m) were recorded. At the end of the first vegetation season in 1982, the dry matter (DM) of foliage in spruce and beech amounted to 35 and 70 kg/ha, respectively. Five years later (1987), these values increased to 770 and 360 kg/ha in spruce and beech, respectively. At a stand age of 21 years, foliage DM was determined to be 11,940 kg/ha for spruce and 3,050 kg/ha for beech. At the same time, the leaf-area index (LAI) was calculated to be 5.55 and 5.94 in spruce and beech, respectively. The method of foliage biomass quantification, based on the determination of foliage DM of mean sample trees and stand density, enabled to acquire complementary data usable in long-term research of the water regime of spruce and beech and simultaneously to provide information on the potential of biomass production and LAI value of both main commercial species in mountain forests of the Czech Republic.

Keywords: Norway spruce; European beech; young stand; foliage biomass; LAI

Production potential studies of forest ecosystems belong to the basic research programs in all countries with a developed forestry sector. Attention is paid not only to timber production but also to other biomass components of forest trees (roots, branches, foliage) as renewable raw materials of our planet.

Given the importance of foliage biomass in the forest nutrient cycle, as well as the potential for utilization by agriculture and industry, many researches in the Czech Republic and Slovakia have quantified the biomass of a forest carbon assimilation component (Oszlányi 1977; Vyskot 1978a,b, 1980, 1985; Vinš, Šika 1981; Chroust 1985; Petráš 1985; Petráš et al. 1985; Lukáč 1992; Réh 1994). In relation to the water regime e.g. Protopopov (1975), Mitchell and Kirby (1990), Landsberg and Gower (1997),

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Chroust (1997) were interested in foliage biomass quantification.

Within the context of a long-term study of the water regime of mountain forests in the Orlické hory Mts., the foliage development of beech and spruce stands was examined from the time of their establishment on clear-felled areas in 1982 until the measurement in 2002.

MATERIAL AND METHODS

Characteristics of experimental stands

An experiment focused on the water balance of mountain forest ecosystems was established in two neighbouring mature stands, pure Norway spruce (*Picea abies* [L.] Karst.) and pure European beech (*Fagus sylvatica* L.), on the Deštné Mountainside in 1976. The stands are situated on a 16° slope of WSW aspect at an altitude of 900 m showing comparable site characteristics (acid site on Cambisol). The active soil reaction in beech (pH/H_2O 4.79) is somewhat more favourable than in spruce (pH/H_2O 4.09), nevertheless, the exchange reaction is identical in both stands (pH/KCl 3.66) and according to Czech criteria it is characterized as intensely acid (ÚHÚL 1973). The plots are of the same size of 40 m × 30 m (0.12 ha).

The pre-harvest water balance of the mature stands was measured from 1st November 1976 to 31st October 1981. During the winter 1981/1982, both stands were clear-cut and replanted with spruce and beech in the following spring. In the spruce plot, three-year-old transplants (mean height 25 cm) were planted at a 1.5 m × 1.5 m spacing (4,600 plants/ha). In beech, two-year-old graded wildlings (mean height ± 28 cm) were used at a square spacing of 1.0 m × 1.0 m (10,000 plants/ha). Since November 1982, the study of water relations in the spruce and beech ecosystem focused on the youngest developmental stages – newly established plantations. Water relations and crown development were simultaneously observed and evaluated during the study. During the winter 1994/1995, the first intensive cleaning was carried out in the spruce stand, every fourth row was removed. Selected trees were removed in the remaining rows. The stand density decreased by more than 50% (from 4,600 to 2,250 trees/ha). The second cleaning was carried out in 2001, when the spruce stand density was reduced to 1,550 trees/ha.

According to tending programs applicable to forest stands in the Czech Republic the beech stand was left without tending felling from 1982 throughout 2002. Only sanitation cuttings were done. During 21 years its density decreased through natural self-reduction by 26% (from 10,000 to 7,440 trees/ha).

Methods of foliage biomass quantification

In order to quantify the foliage biomass of both stands we determined crown foliage weight and leaf area of an average sample tree and stand density. We estimated the average sample tree every year based on mean stand height until the age of 14 years (height of all trees was measured). Afterwards, we estimated mean stand height (height of 25% of the trees was measured) and particularly mean diameter at breast height (dbh of all trees was measured). The foliage biomass of each of the two tree species was determined from 20 tree samples at the stage of young plantations and from 10 tree samples at the stage of young growth (the details follow).

The stage of young plantations (1 to 10 years)

Dry matter (DM) biomass data of spruce foliage in the stage of unclosed plantations (age up to 9 years) were taken from measurements of Chroust (1985). Smoothing data of the needle DM of sample spruce trees from a height of 0.2 m to a height of 3.5 m were used (see Fig. 1).

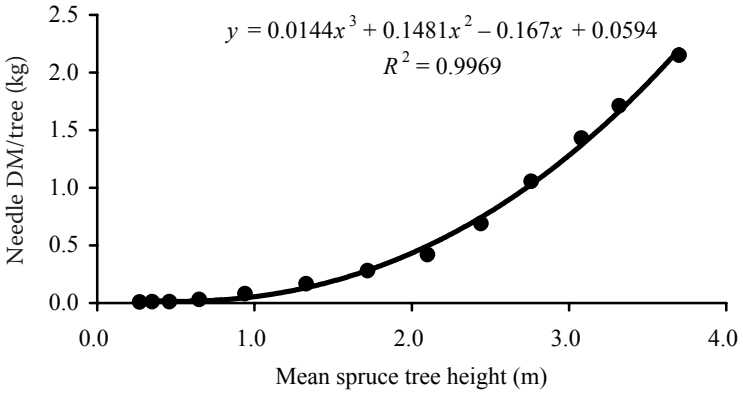

Fig. 1. Mean tree needle dry matter as related to mean tree height in the unclosed Norway spruce stand. Data were obtained with trees at an age from 1 to 13 years

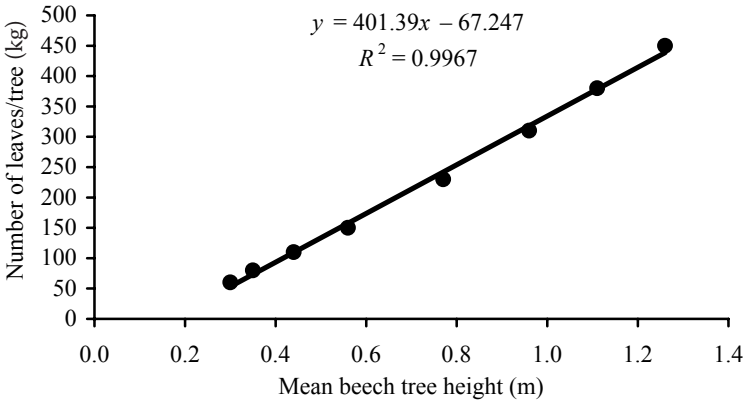

Fig. 2. Number of beech leaves per tree as related to mean tree height in the unclosed European beech stand. Data were obtained with trees at an age from 1 to 8 years

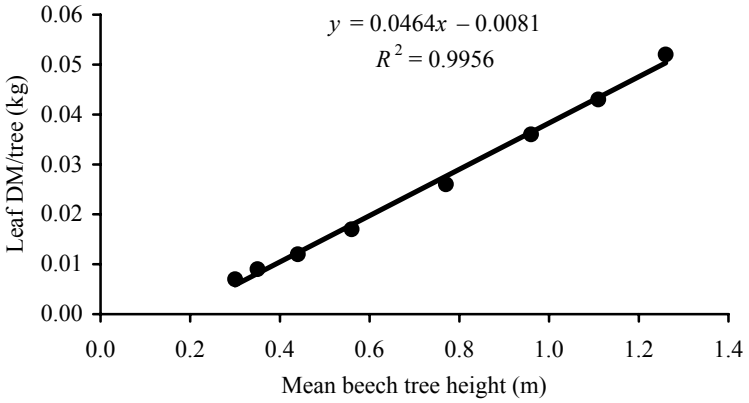

Fig. 3. Mean tree leaf dry matter as related to mean tree height in the unclosed European beech stand. Data were obtained with trees at an age from 1 to 8 years

DM of beech foliage biomass of sample trees in unclosed plantations was determined at two examinations. The first was carried out in autumn 1988, when all leaves were counted in 60 sample trees of height between 0.3 m and 1.8 m. Simultaneously, all leaves were taken from 20 sample trees, dried at 105°C and weighed to determine the mean leaf DM. The second examination was carried out by the same method four years later by Tydlita (1992). He determined numbers of leaves and subsequently their DM from 22 sample trees of beech 1.1 to 3.0 m tall. Correlation between the height of sample trees and the number of leaves is expressed in Fig. 2, correlation between beech height and the crown leaf weight is shown in Fig. 3.

The stage of young growth (11 to 21 years)

The foliage DM biomass of spruce and beech trees was determined by destructively sampling trees in 1995, 1999 and 2002.

Both from the spruce and from the beach plot, ten sample trees were chosen to include subdominant, codominant and dominant trees of the stand. From the sample trees all branches were sawn from the trunks and after pre-drying at room temperature all

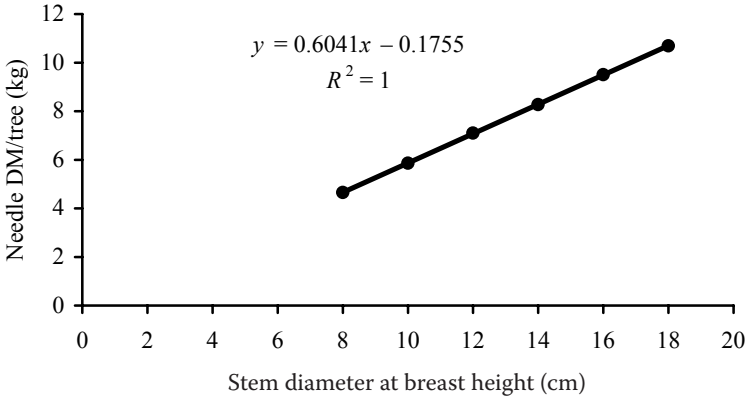

Fig. 4. Needle dry matter of spruce trees as related to dbh in a 21-year-old Norway spruce stand

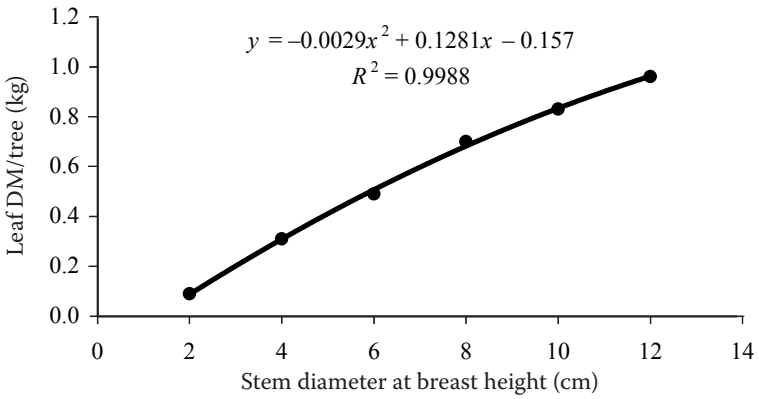

Fig. 5. Leaf dry matter of beech trees as related to dbh in a 21-year-old European beech stand

leaves were removed from them. Subsequently, the leaves of particular trees were dried at 105°C and weighed. Correlations between the DM of sample tree leaves and dbh are depicted in Figs. 4 and 5.

Moreover, during studies carried out in 1999 and 2002, we determined mean leaf weight and area for each spruce and beech sample tree. Thus, the number of leaves could be calculated in all sample

Table 1. Development of the Norway spruce stand on a long-standing research plot in the Orlické hory Mts. in the years 1982 to 2002 (age from 1 to 21 years)

Year of measurement	Stand age (years)	Number of trees (ha)	Mean height (m)	Mean dbh (cm)	DM of foliage		Foliage number mean tree (tree)	Leaf area		LAI
					mean tree (kg)	stand (kg/ha)		mean tree (m^2)	stand (m^2/ha)	
1982	1	4,600	0.27	n.d.	0.008	35	2,900	0.04	170	0.02
1983	2	4,600	0.35	n.d.	0.010	45	3,600	0.05	220	0.02
1984	3	4,600	0.46	n.d.	0.012	55	4,300	0.06	260	0.03
1985	4	4,600	0.65	n.d.	0.031	140	11,000	0.14	670	0.07
1986	5	4,600	0.94	n.d.	0.080	370	28,000	0.37	1,700	0.17
1987	6	4,600	1.33	n.d.	0.168	770	59,000	0.78	3,600	0.36
1988	7	4,600	1.72	n.d.	0.280	1,290	100,000	1.31	6,000	0.60
1989	8	4,600	2.10	n.d.	0.420	1,930	149,000	1.96	9,000	0.90
1990	9	4,600	2.44	n.d.	0.690	3,170	246,000	3.23	14,900	1.49
1991	10	4,600	2.76	2.6	1.055	4,850	375,000	4.92	22,600	2.26
1992	11	4,600	3.08	2.9	1.430	6,580	509,000	6.67	30,700	3.07
1993	12	4,600	3.32	3.3	1.710	7,870	609,000	7.97	36,700	3.67
1994	13	4,600	3.70	3.8	2.150	9,890	765,000	10.02	46,100	4.61
1995	14	2,383	4.26	4.3	2.551	6,080	908,000	11.89	28,300	2.83
1996	15	2,250	4.74	4.8	2.767	6,230	985,000	12.30	29,000	2.90
1997	16	2,250	5.25	5.4	2.997	6,740	1,067,000	13.97	31,400	3.14
1998	17	2,250	5.80	6.0	3.245	7,300	1,155,000	15.13	34,000	3.40
1999	18	2,250	6.46	6.8	3.900	8,780	1,388,000	18.18	40,900	4.01
2000	19	2,250	7.40	7.8	4.500	10,130	1,601,000	20.98	47,200	4.72
2001	20	1,550	9.15	11.7	6.750	10,460	2,402,000	31.47	48,800	4.88
2002	21	1,550	10.10	12.9	7.703	11,940	2,733,000	35.80	55,500	5.55

trees as well as the total area of their leaves. At the same time, leaf area index (LAI) values for both stands could be complementarily determined. To calculate LAI, the surface area of the leaves (needles) was summed and divided by the ground surface area that they occupied. Both areas were measured in the same units, so LAI was dimensionless. We should note that the estimation of an average sample tree faces a number of pitfalls. So long as the trees are free to grow, the common situation in the early development of young plantations determines correlations between the height of trees and foliar biomass. In the rapidly changing microenvironments of closing and closed canopies, the determination of an average sample tree is more problematic. According to the height and dbh of trees, the amount of leaves in each tree is dependent on its actual social position in the stand and on the available growing space. Therefore, data given in the paper should be considered to be of a complementary character.

However, results of studies from 1999 and 2002 characterizing growth parameters of 18-year-old or 21-year-old spruce (height 5.1 to 10.8 m) and beech (height 3.2 to 6.6 m) sample trees and the amount of their foliar biomass are of an important information value.

RESULTS AND DISCUSSION

The development of a spruce and beech stand established by artificial regeneration on clear-felled areas in 1982 is documented until 2002 by means of Tables 1 and 2. In addition to basic mensurational parameters (age, density, height and since 1995

Table 2. Development of the European beech stand on a long-standing research plot in the Orlické hory Mts. in the years 1982 to 2002 (age from 1 to 21 years)

Year of measurement	Stand age (years)	Number of trees (ha)	Mean height (m)	Mean dbh (cm)	DM of foliage		Foliage number mean tree (tree)	Leaf area		LAI
					mean tree (kg)	stand (kg/ha)		mean tree (m^2)	stand (m^2/ha)	
1982	1	10,000	0.30	n.d.	0.007	70	60	0.13	1,340	0.13
1983	2	10,000	0.35	n.d.	0.009	85	80	0.17	1,740	0.17
1984	3	10,000	0.44	n.d.	0.012	120	110	0.23	2,310	0.23
1985	4	10,000	0.56	n.d.	0.017	170	150	0.33	3,260	0.33
1986	5	10,000	0.77	n.d.	0.026	260	230	0.50	5,000	0.50
1987	6	10,000	0.96	n.d.	0.036	360	310	0.69	6,900	0.69
1988	7	10,000	1.11	n.d.	0.043	430	380	0.83	8,300	0.83
1989	8	10,000	1.26	n.d.	0.052	520	450	1.00	10,000	1.00
1990	9	8,500	1.55	n.d.	0.088	750	770	1.69	14,400	1.44
1991	10	8,500	1.74	n.d.	0.127	1,080	1,110	2.44	20,700	2.07
1992	11	8,500	2.01	n.d.	0.156	1,330	1,360	3.00	25,500	2.55
1993	12	8,500	2.31	n.d.	0.192	1,630	1,680	3.69	31,400	3.14
1994	13	8,500	2.65	n.d.	0.235	2,000	2,050	4.51	38,400	3.84
1995	14	8,420	3.02	2.6	0.260	2,190	2,270	5.00	42,100	4.21
1996	15	8,220	3.33	2.8	0.322	2,650	2,810	6.19	50,900	5.09
1997	16	8,220	3.67	3.4	0.340	2,790	2,970	6.54	53,700	5.37
1998	17	8,190	3.87	3.6	0.352	2,880	3,070	6.77	55,400	5.54
1999	18	8,190	4.00	4.2	0.370	3,030	3,230	7.11	58,300	5.83
2000	19	8,190	4.25	4.5	0.385	3,150	3,360	7.40	60,600	6.06
2001	20	8,190	4.50	4.8	0.399	3,270	3,480	7.67	62,800	6.28
2002	21	7,440	4.78	5.1	0.410	3,050	3,620	7.98	59,400	5.94

Table 3. Characteristics of Norway spruce stand at the age of 21 years in 2002

Diameter degree	Number of trees (ha)	Mean tree					Spruce stand		
		height (m)	dbh (cm)	b.a. (m^2)	volume (m^3)	DM of foliage (kg)	b.a. (m^2/ha)	volume (m^3/ha)	DM of foliage (kg/ha)
8	17	8.6	8.2	0.0053	0.02	4.65	0.0899	0.3	80
10	153	9.2	10.3	0.0083	0.03	5.86	1.2767	4.6	900
12	673	9.9	11.9	0.0112	0.06	7.10	7.5421	40.4	4,780
14	460	10.5	13.8	0.0149	0.07	8.27	6.8751	32.2	3,800
16	221	11.1	15.8	0.0195	0.10	9.50	4.3173	22.1	2,100
18	26	11.7	17.4	0.0238	0.14	10.69	0.6072	3.6	280
Total	1,550						20.7084	103.2	11,940

also dbh) in each of the years, DM and leaf area of foliage of an average tree are given including a complementary conversion for the whole stand. Finally, calculated LAI values are also presented.

Basic mensurational parameters

The height growth of both plantations showed a similar rate during the first three years after planting. Since 1985, however, spruce height increment was greater; 10 years after planting, a difference in the mean height of both species amounted to 1 m (spruce 2.76 m, beech 1.74 m) and 15 years after planting, it was 1.4 m (spruce 4.74 m, beech 3.33 m). Noticeable differences in the development of both stands were starting just in this period when spruce density was reduced by more than 50% through the first cleaning in 1995. The second tending measure in 2001 resulted in a decrease in the number of spruce trees to even 1,550 trees/ha. These measures were carried out according to intentions of tending programs for spruce stands in the Czech Republic. Particularly subdominant trees of the lowest diameter classes were removed (see the increase in the mean height after the second measure in 2001 as against 2000). Moreover, the released space was used by the remaining dominant and codominant spruce trees for dynamic height and diameter increments. Thus, height increment amounted to about 100 cm/year within the 3 years. The mean height of spruce was 10.1 m at an age of 21 years, mean dbh amounted to 12.9 cm (see Table 1).

In the Czech Republic, on the other hand, tending programs for beech are based on the high stand density at an age of 20–30 years (advance growth, young plantation and pole stage stand). Thus, a condition is created to achieve the required quality of beech timber at rotation age. In the Orlické hory Mts., the

Table 4. Characteristics of European beech stand at the age of 21 years in 2002

Diameter degree	Number of trees (ha)	Mean tree					Beech stand		
		height (m)	dbh (cm)	b.a. (m^2)	volume (m^3)	DM of foliage (kg)	b.a. (m^2/ha)	volume (m^3/ha)	DM of foliage (kg/ha)
2	1,557	3.4	2.2	0.0004	0.0012	0.09	0.60833	1.9	140
4	2,388	4.3	3.9	0.0012	0.0028	0.31	2.91002	6.7	740
6	1,771	5.1	5.9	0.0028	0.0052	0.49	4.90479	9.2	870
8	1,192	6.0	7.9	0.0048	0.0088	0.70	5.77922	10.5	830
10	371	6.9	9.9	0.0077	0.0200	0.83	2.87043	7.4	310
12	161	7.8	11.4	0.0102	0.0350	0.96	1.63787	5.6	160
Total	7,440						18.71070	41.3	3,050

development of the beech stand was, therefore, left to its natural self-reduction. The initial density of 10,000 trees/ha decreased by 26% to 7,440 trees/ha in the course of 21 years (Table 2). The stand began to be markedly differentiated in its height particularly since the age of 15 years. In the period of the examination in 2002, the height range amounted to already 3.4 to 7.8 m (see Table 4). Considering the substantial number of subdominant but viable beech trees, the mean height of beech at the age of 21 years amounted merely to 4.7 m. Therefore, the mean annual height increment ranged only from 22 to 25 cm/year within the three years.

In Tables 3 and 4, basic mensurational data are given of both stands obtained during the inventory in 2002 and differentiated according to diameter classes. At the age of 21 years, stand basal area (b.a.) in spruce reached 20.7 m^2/ha and in beech 18.7 m^2/ha. In this period, the total growing stock amounted to 103 and 41 m^3/ha in spruce and beech, respectively.

Quantification of foliar biomass

In the first three years after planting, the foliage weight of average sample tree was similar (in 1982 and 1984 it was 7–8 g and 12 g DM per tree, respectively). In the following years, the amount of the needle biomass of spruce increased rapidly (7-year-old average sample tree 0.28 kg DM, 10-year-old average sample tree 1.06 kg DM). On the other hand, the DM of beech was markedly lower, only 0.04 kg per tree at 7 years and 0.13 kg at 10 years.

In the period from 1991 to 1994, height increment in spruce and beech ranged between 24 and 38 cm and both young stands were in the stage of a closing thicket. In 1994 the DM of needles of an average spruce tree amounted to 2.15 kg and DM of leaves of an average beech tree was 0.235 kg.

After the first intensive cleaning in winter 1994/1995 the spruce stand density decreased to 2,250 trees/ha. Particularly owing to this radical measure, lower whorls of branches did not die and the weight of needles of spruce trees continued in its rapid growth. The DM of spruce needles was 3.90 kg in 1999 (Table 1). After a further reduction of density to 1,550 trees/ha, the value increased further to reach 7.70 kg in 2002.

The beech plot was left to development without tending felling. During 21 years the stand density decreased by natural self-reduction to 7,440 trees/ha. The amount of leaf biomass increased in the majority of trees but not so rapidly as in the spruce plot. Moreover in closed parts of the thicket, completely shaded lower branches began to die gradually. At the measurement in 2002, the average beech sample tree was characterized by the height of 4.8 m, dbh 5.1 cm and DM of leaves 0.41 kg/tree (Table 2).

Table 5. Parameters of 18-year-old spruce sample trees (in 1999)

Sample tree No.	Height (m)	dbh (cm)	Foliage number (tree)	DM of one leaf (g)	Area of one leaf (cm^2)	DM of sample tree leaves (kg)	Leaf area of sample tree (m^2)
1	8.0	7.3	1,865,000	0.0025	0.14	4.65	26.1
2	6.9	9.3	2,670,000	0.0022	0.11	5.89	29.4
3	6.9	8.4	680,000	0.0032	0.11	2.02	7.5
4	6.8	7.2	627,000	0.0027	0.15	1.67	9.4
5	6.5	9.2	1,675,000	0.0036	0.11	6.04	18.4
6	6.3	6.7	1,070,000	0.0024	0.13	2.57	13.9
7	6.3	6.6	1,330,000	0.0032	0.18	4.29	23.9
8	5.9	7.9	1,296,000	0.0030	0.16	3.83	20.7
9	5.9	4.3	823,000	0.0024	0.13	1.98	10.7
10	5.1	5.8	1,065,000	0.0025	0.13	2.65	13.8
Mean	6.46	7.3	1,310,100	0.00277	0.135	3.559	17.380
Smpl. standard deviation	0.77	1.5	624,467	0.00045	0.023	1.620	7.498
Variation coefficient (%)	12	21	48	16	17	46	43

Comparable results were obtained by Vyskot (1978b) during his studies in spruce thickets in the Bohemian-Moravian Upland. According to his measurements, the DM of needles of a 24-year-old codominant sample tree (h 9.5 m, dbh 8.4 cm) amounted to 2.37 kg, that of a subdominant sample tree (h 7.2 m, dbh 5.5 cm) 0.77 kg.

Data on the biomass production of leaves of a 20-year-old beech thicket coming from natural regeneration in the Vihorlat Mts. were published by Réh (1994). Through the analysis of 34 sample trees it is possible to find that in codominant and dominant trees (height 6.5 to 9 m) the DM of their leaves ranges usually between 0.15 and 0.59 kg, which corresponds to our data from the Orlické hory Mts.

Tables 1 and 2 show data on the foliage weight from both plots converted to one hectare. These data were calculated by multiplying the number of trees per ha and the DM of leaves of an average sample tree. It is necessary to note again that these are data obtained on the basis of an analysis of 30 sample trees of spruce and 30 sample trees of beech. From the stage of thickets, the amount and weight of foliage are rather dependent on the crown size and dbh of trees than on the tree height (see Figs. 4 and 5).

The weight of needles in the spruce stand increased rapidly (after planting in 1982 it amounted to 35 kg per ha, after 5 years 370 kg/ha, after 10 years already 4,850 kg/ha and at the age of 13 years before a heavy cleaning 9,890 kg/ha). In the following year, due to a 50% spruce tree reduction, the needle biomass decreased to 6,080 kg/ha. At the examination carried out in 1999, the DM of needles got to 8,780 kg/ha and during the examination in 2002 even to 11,940 kg/ha.

The naturally developing beech stand (no tending measures until then) showed a regular increase in the foliage biomass. After planting, the DM of leaves amounted to 70 kg/ha, after 5 years to 260 kg/ha, after 10 years to 1,080 kg/ha and after 15 years to 2,650 kg/ha. At the examination in 1999 at the age of 18 years, the DM of leaves amounted to 3,030 kg/ha and in 2002 at the age of 21 years 3,050 kg/ha.

Numerical information on destruction analysis of sample trees in 1999 and 2002

The method of destruction analysis of 10 sample trees from each of the stands carried out in 1995, 1999 and 2002 made it possible to acquire a number of important data. The data from 1999 and 2002 studies on the spruce plot are presented in Tables 5 and 6, on the beech plot in Tables 7 and 8.

At the age of 18 years, the height of spruce sample trees ranged from 5.1 to 8.0 m and dbh from 4.3 to 9.3 cm. Dominant trees showed the highest amount of needle biomass; however, no close significant dependence on the mensurational parameters h and dbh was noticed. For example, in the highest sample tree No. 1 (h 8.0 m, dbh 7.3 cm), the DM of needles amounted to 4.65 kg but in markedly lower sample tree No. 5 (h 6.5 m, dbh 9.2 cm), it was substantially greater, equal to 6.04 kg. Similarly, higher and thicker sample tree No. 3 showed the half amount of assimilatory apparatus (2.02 kg) compared to sample tree No. 7 with markedly lower mensurational parameters (4.29 kg) – see Table 5.

The period 1999 to 2002 (age 18 to 21 years) was characterized by an extraordinarily dynamic increase in mensurational parameters and biomass of needles in spruce. It is documented by data in Table 6 when the DM of needles in 21-year-old sample trees ranged between 4.8 and 14.3 kg. As for other fact-

Table 6. Parameters of 21-year-old spruce sample trees (in 2002)

Sample tree No.	Height (m)	dbh (cm)	Foliage number (tree)	DM of one leaf (g)	Area of one leaf (cm^2)	DM of sample tree leaves (kg)	Leaf area of sample tree (m^2)
1	10.8	15.6	4,913,000	0.0029	0.132	14.34	64.8
2	9.7	12.3	2,865,000	0.0026	0.121	7.60	34.6
3	9.7	12.2	2,894,000	0.0025	0.120	7.10	34.8
4	8.8	11.6	2,367,000	0.0034	0.129	8.10	30.5
5	8.8	10.4	1,550,000	0.0031	0.125	4.80	19.4
Mean	9.56	12.4	2,917,800	0.0029	0.125	8.388	36.820
Smpl. standard deviation	0.83	1.9	1,240,810	0.0004	0.005	3.559	16.847
Variation coefficient (%)	9	16	43	13	4	42	46

Table 7. Parameters of 18-year-old beech sample trees (in 1999)

Sample tree No.	Height (m)	dbh (cm)	Foliage number (tree)	DM of one leaf (g)	Area of one leaf (cm^2)	DM of sample tree leaves (kg)	Leaf area of sample tree (m^2)
1	6.4	9.5	7,800	0.1210	26.66	0.94	20.8
2	6.4	9.5	5,030	0.1558	27.71	0.78	13.9
3	5.5	6.2	5,600	0.1268	24.33	0.71	13.6
4	5.4	8.3	6,220	0.1221	22.44	0.76	13.9
5	5.3	6.6	7,420	0.0836	17.24	0.62	12.8
6	5.1	6.5	7,310	0.0958	18.10	0.70	13.2
7	5.1	5.5	4,440	0.1188	21.17	0.53	9.4
8	4.3	5.5	5,780	0.1246	21.31	0.72	12.3
9	4.3	4.7	4,700	0.0957	25.05	0.45	11.8
10	3.2	5.3	3,150	0.1123	20.63	0.35	6.5
Mean	5.10	6.8	5,745	0.1157	22.464	0.656	12.820
Smpl. standard deviation	0.98	1.7	1,482	0.0203	3.464	0.173	3.647
Variation coefficient (%)	19	26	26	18	15	26	28

finding results it is possible to notice, for example, the number of needles in particular sample trees in 2002 (1.55 to 4.91 million per tree) and needle area (19.4 to 64.8 m^2 per tree).

In 1999, 10 sample trees for destruction analysis of beech were taken particularly from the dominant and codominant part of the whole stand spectrum (h 3.2 to 6.4 m; dbh 4.7 to 9.5 cm) – see Table 7. The

Table 8. Parameters of 21-year-old beech sample trees (in 2002)

Sample tree No.	Height (m)	dbh (cm)	Foliage number (tree)	DM of one leaf (g)	Area of one leaf (cm^2)	DM of sample tree leaves (kg)	Leaf area of sample tree (m^2)
1	6.6	6.9	4,140	0.1528	19.52	0.63	8.08
2	6.5	6.5	3,150	0.1169	22.41	0.37	7.06
3	6.5	5.1	2,480	0.1208	20.73	0.30	5.13
4	6.3	5.7	3,880	0.1168	23.20	0.45	8.99
5	6.2	8.7	3,800	0.1271	26.40	0.48	10.03
6	6.0	5.6	3,080	0.1580	18.75	0.36	5.78
7	5.8	6.1	4,070	0.0691	20.14	0.28	8.19
8	5.2	5.1	2,920	0.1121	27.15	0.33	7.94
9	4.9	3.5	2,530	0.0749	17.40	0.19	4.40
10	4.3	3.7	1,900	0.0858	20.12	0.16	3.83
Mean	5.83	5.7	3,195	0.1134	21.582	0.355	6.943
Smpl. standard deviation	0.79	1.5	761	0.0298	3.201	0.139	2.065
Variation coefficient (%)	14	27	24	26	15	39	30

DM of leaves ranged from 0.35 kg in the lowest beech to 0.94 kg in the highest and thickest sample tree. The number of leaves of one tree ranged from 3,150 to 7,800 and their area ranged from 6.5 to 20.8 m^2.

In 2002, on the other hand, 10 sample trees of beech were taken from the codominant and subdominant layer (h 4.3 to 6.6 m; dbh 3.5 to 8.7 cm) – see Table 8. The DM of leaves ranged from 0.16 kg in beech trees of the smallest dbh to 0.63 kg in sample trees of the largest dbh. The number of leaves of one tree ranged from 1,900 to 4,140 and their area ranged from 3.8 to 10.0 m^2.

LAI values

In this paper, the leaf area index (LAI) was calculated for each year from the stand density (number of trees/ha) and from the area of leaves of an average sample tree. Its values are given in Tables 1 and 2. Considering the method of determination, LAI is only of a complementary value similarly like the DM of foliage of whole stands.

In the period of unclosed young plantations (age 1 to 5 years) LAI is practically without informative value. The LAI of 1.0 was achieved in both young stands at the age of 8 to 9 years. In the course of subsequent years, LAI rapidly increased (13-year-old spruce 4.61, beech 3.84).

After the thinning and reduction in the number of trees by more than 50%, LAI of spruce decreased to 2.83 at an age of 14 years. At the examination in 2002 (age 21 years; 1,550 spruce trees/ha; leaf area of the mean sample tree 35.8 m^2) its value amounted to 5.55.

In the beech stand, the increase in LAI was preserved throughout the stand development. A moderate decrease to the value 5.94 was recorded at the measurement in 2002 when due to natural self-reduction about 750 subdominant beech trees per ha died.

CONCLUSION

Findings on the development of foliage biomass including LAI and the growth of spruce and beech stands in the juvenile stage (age 1 to 21 years) represent a special complementary study to the long-term investigation of water balance components on the experimental forest hydrology area Deštné Mountainside. The results can be summarized as follows:

– Both stands established by artificial regeneration (spruce 4,600 plants/ha, beech 10,000 plants/ha) on clear-felled areas grew very well during the whole study period from 1982 to 2002. After overcoming the transplantation shock, at the age of 5 years the mean height of spruce and beech plantations amounted to 94 and 77 cm, respectively. Ten years after planting both stands were of the character of a closing thicket (height: spruce 2.76 m, beech 1.74 m). During the inventory in 2002, the spruce stand showed a character of a small-pole stage stand (h = 10.1 m; dbh = 12.9 cm) and the beech stand a character of a closed thicket (h = 4.8 m; dbh = 5.1 cm). Lower parameters of beech are affected by the large number of subdominant and suppressed trees.

In research plots in the Orlické hory Mts., the DM of foliar biomass of average sample tree of spruce and beech was characterized by the following values: in the year of planting – spruce 0.008 kg, beech 0.007 kg; in 5 years – spruce 0.080 kg, beech 0.026 kg; in 10 years – spruce 1.06 kg, beech 0.13 kg; in 15 years – spruce 2.77 kg, beech 0.32 kg; in 21 years – spruce 7.70 kg, beech 0.41 kg.

The conversions of foliage biomass for whole stands depend on stand density and consequently are related to tending programs for stands of special tree species. The beech stand was not prescribed any tending felling and its density naturally decreased from 10,000 to 7,440 plants/ha in the course of 21 years. Beech showed a practically steady increase in the weight of leaves from 70 kg/ha in the stage of planting up to 3,050 kg/ha in 2002.

Similarly, in the spruce stand, production of needle biomass increased until 13 years of age of the thicket (35 kg/ha in the year of planting, 9,890 kg/ha in 1994). The first heavy cleaning (stand density reduction by 50%) was immediately reflected in the reduction in needle biomass to 6,080 kg/ha in the subsequent year 1995. The released space markedly supported the growth of the remaining trees both in vertical and horizontal direction and so as early as in 1999, the total production of needles increased to 8,780 kg DM/ha. Even after the second cleaning (reduction to 1,550 trees/ha), the DM of needles increased to 11,940 kg/ha in 2002.

LAI increased in the course of the whole time series of the stand development and reached the value 5.55 in spruce and 5.94 in beech at an age of 21 years.

The method of foliage biomass quantification, based on the determination of foliage DM of average sample trees and stand density, enabled to acquire complementary data usable in long-term research of the water regime of spruce and beech (Kantor 1992, 1995; Krečmer et al. 2003; Šach et al. 2006). Simultaneously information was provided on the potential of biomass production and LAI value of both main commercial species in mountain forests of the Czech Republic.

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Vývoj listové biomasy mladého porostu smrku a buku na dlouhodobé výzkumné ploše vodní bilance v Orlických horách

ABSTRAKT: Výzkum vývoje listové biomasy včetně LAI a růstu smrkového a bukového porostu v juvenilní fázi (1–21 let) rezultoval ve zvláštní doplňkovou studii k dlouhodobému sledování prvků vodní bilance na výzkumné ploše Deštenská stráň. Experiment byl umístěn v Orlických horách v nadmořské výšce 900 m na plochách holých sečí. Smrková kultura byla vysazena ve sponu 1,5 × 1,5 m (4 600 ks/ha), buková ve sponu 1,0 × 1,0 m (10 000 ks na ha). Podle výchovných programů používaných pro lesní porosty v ČR se ve smrku realizovaly dva výchovné zásahy (v r. 1995 a 2001), v buku nebyla do věku 20 let výchova plánována. V roce 2002 bylo na plochách po provedených výchovných zásazích registrováno 1 550 smrků/ha (střední výška 10,1 m) a 7 440 buků/ha (střední výška 4,8 m). Na konci prvního vegetačního období v roce 1982 činila hmotnost sušiny asimilačních orgánů ve smrku 35 kg/ha a v buku 70 kg/ha. Po pěti letech (v roce 1987) se tyto hodnoty zvýšily na 770 kg/ha ve smrku a na 360 kg/ha v buku. V roce 2002 (věk porostu 21 let) byla stanovena hmotnost sušiny jehličí ve smrku 11 900 kg/ha a hmotnost sušiny listů v buku 3 050 kg/ha. Souběžně byl dopočten index listové plochy (LAI), který ve věku 21 let dosáhl ve smrku

hodnoty 5,55, v buku 5,94. Metoda kvantifikace listové biomasy založená na stanovení sušiny listoví průměrných vzorníků a hustoty porostů umožnila získat doplňující údaje využitelné při dlouhodobém výzkumu vodního režimu smrku a buku a současně podat informace o potenciální produkci biomasy a hodnotách LAI obou hlavních hospodářských dřevin horských lesů ČR.

Klíčová slova: smrk ztepilý; buk lesní; mladý porost; biomasa; LAI

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